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FROM WIND-TUNNEL MEASUREMENTS

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NATIONAL ADVISORY COMMITTEE BOB AERONAUTICS

ADVANCE ~~RESEARCH~~ REPORT

ELEVATOR STICK FORCES IN SPINS AS COMPUTED
FROM WIND-TUNNEL MEASUREMENTS

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SUMMARY

Data from wind-tunnel measurements of elevator hinge-moment coefficients at high angles of attack are utilized in estimating elevator stick forces in spins.

The analysis indicates that elevator forces on several current airplanes will be so high that the pilot will be unable to push the stick to the neutral position. Large nose balances involve danger of the elevator locking in the full-up position. Trimming tabs can be used to reduce the elevator stick force. Stick forces will be greater in steep spins than in flat spins.

INTRODUCTION

Considerable difficulty has recently been experienced in the recovery of airplanes from spins because the pilot has been unable to apply a sufficient force to move the control surfaces. This problem is growing more acute with the present trend in airplane design toward increased weights with accompanying higher velocities. The manipulation of rudder, ailerons, and elevator, singly or in combination, is necessary to effect a recovery from a spin; therefore, information on the required forces for all three control surfaces is essential. Because most control-force investigations have been carried out in the normal flight range, very little information is available for airplanes in spinning attitudes.

Measurements of elevator hinge-moment coefficients on a model at high angles of attack were recently made in the LMAL 7- by 10-foot tunnel (reference 1). In the present paper, these results are applied in estimating the elevator hinge moments and the corresponding stick forces in spins. For an airplane in a typical spinning attitude, the

effects of various blunt- and sharp-nose balances are compared and the effectiveness of a trailing-edge tab is shown. In addition, the stick forces for four specific current airplanes have been computed.

For most of the current airplanes likely to be spun, the rudder is the predominant control in the recovery from spins. In many cases, however, the elevator must be neutralized or reversed in order to effect satisfactory recovery. Frequently the position of the ailerons is of considerable importance. It must be realized, therefore, that the present study, in which only elevator forces are considered, covers only one phase of the problem of control forces in spins. Because the original measurements were made on one specific tail unit, the results obtained when the data are applied directly to other tail arrangements without corrections for aerodynamic variables must be considered only rough estimates and should be interpreted qualitatively. In the present paper, only the hinge moments at a given elevator deflection are considered; the effectiveness of the elevator in producing lift is discussed in reference 1.

METHOD OF COMPUTATION

The elevator hinge-moment coefficients used in the present study were taken directly from the data of reference 1. These data were obtained from measurements for a horizontal tail surface mounted on the fuselage of a typical pursuit airplane. The rotation of the spin was not simulated in the tests of reference 1. The fuselage was tested to a range of angles of attack from about -10° to 47° and to a range-of-yaw angles from -10° to 45° . The coefficients presented show the effect of different amounts of elevator nose balance and of a trailing-edge tab for a range of elevator deflection.

The conditions at the tail for representative spins were obtained from unpublished data from the NACA 15-foot free-spinning tunnel.

For the application of the test data, the angles of attack and yaw and the velocity at the horizontal tail were obtained from the spin-tunnel data. The angle of attack at the tail plane for zero tail setting with respect to the wing was taken to be the same as the angle of attack

on the wing at the plane of symmetry. The angle of yaw at the tail was computed as

$$\psi = \frac{\Omega R_T}{V} - \phi$$

where

Ω angular velocity in spin

V rate of descent

R_T distance from axis of rotation to elevator hinge axis

ϕ angle between span axis and horizontal

The elevator hinge-moment coefficients corresponding to these angles were taken from the data of reference 1 and were assumed to apply directly to the specific tails under consideration. The full-scale hinge moments were then calculated for the density at the spin-task altitude. The stick forces were determined from the hinge moments on the assumption of uniform gearing between the elevator and stick, for which an 18-inch movement of the stick corresponded to a 50° movement of the elevator.

This procedure gives the effects due to the aerodynamic forces and involves the assumption that the correction for any elevator mass unbalance, control-system mass forces, and friction will be small. The effects of rotation are also neglected. It is appreciated that, as a result of the rotation of the spinning airplane, there is a variation in angle of attack along the tail span which amounts to a difference of 5° between the value at the center and the tip of the tail plane. As the tail plane is well above the stall in the spin, it is believed that this variation of angle of attack will not have a significant effect on the hinge moments. The corresponding variation in the magnitude of air velocity across the tail span is less than 1 percent.

In using the test data from reference 1 to compute the stick forces of the various airplanes, no correction was made for the ratio of elevator area to tail-plane area nor for the tail-plane airfoil thickness, aspect ratio, and plan form. Although it was realized that these factors would affect the hinge moments, it was felt that the information available was insufficient to form the basis for

accurate corrections. The dimensional characteristics of the tail plane used in the tests of reference 1 are presented for comparison with the dimensional characteristics of the tail planes to which the data are currently applied. (See table I and figs. 1 to 5.)

RESULTS AND DISCUSSION

Results are presented that show the effects of various pose balances and of a trailing-edge tab on the stick forces for the P-36A airplane (referred to as airplane B later in the text;) spinning under the following conditions:

Angle of attack, α , deg	.....	45
Angle between span axis and horizontal, ϕ , deg	.....	0
Rate of descent, V , ft/sec	.....	161
Yaw angle at tail, deg	.....	0
Altitude, ft	.....	12,000

The yaw at the tail was taken as zero because the data of reference 1 cover the effect of yaw for only two elevator deflections and it was desired to plot stick force against elevator angle. The available data indicate the effect of moderate yaw to be negligible.

The stick forces for various elevator angles are computed for the same basic spin condition to evaluate the force required to push the stick forward rapidly in such a way that the motion is completed before the spin can be altered by the changed elevator position. Figure 6, which is based on information from reference 2 and shows the maximum elevator stick forces that a pilot can apply with one hand, is presented for comparison.

Effect of Nose Balances

The stick-force variation for various nose balances is shown in figure 7. Little difference is shown between the trends for sealed and unsealed controls. Data for the balanced surfaces were not available for elevator-up deflections larger than 20° because the balance nose unported at larger deflections.

The plain elevator shows a larger force variation than any of the balanced surfaces throughout the deflection

range investigated. The high pull force for the **Pull-up** elevator deflection is a very desirable feature because the pilot has to exert a pull to hold the stick back in the steady spin. When the elevator approaches neutral, however, the aerodynamic force acts in the opposite direction, and the pilot must exert considerable effort to **neutralize** the elevator. It is probable that the elevator can be neutralized even though the force required to hold it at neutral is high.

The 35-percent blunt-nose balance requires a fairly large push to move the stick when it is back but has an advantage over the plain elevator in that a smaller force is required to hold the stick neutral. Inasmuch as the push that a pilot is capable of exerting on the stick is least when the stick is back (see fig. 6), there is some danger of the elevator locking with the 55-percent blunt-nose balance.

The 35-percent sharp-nose balance is similar in affect to the 35-percent blunt-nose balance at low elevator deflections but, when the elevator has a large upward deflection, the force required to **begin** moving the stick **forward** is very **small**. There is no danger of the elevator locking at the 20° up position when this balance is installed.

The elevator with sealed 50-percent blunt-nose balance is overbalanced in that the required push on the stick becomes smaller as the elevator is moved down. This decrease in stick force gives the wrong stick "feel" and may give the pilot the erroneous impression that the elevator is **fa-**effective. With this balance unsealed, the stick-force curve is irregular but again shows overbalance in part of the range.

The 50-percent sharp-nose design shows overbalance for up deflections exceeding 15° . For both 50-percent balance types there is serious danger of the elevator locking in the spin. It should be appreciated that the 50-percent blunt-nose balance, according to reference 1, also shows overbalance in the normal flight range. A desirable feature of the 50-percent balance is the low force required to hold **ths** elevators in neutral.

It should be realized that, for both the 35-percent and the 51-percent balances, elevator-up deflections exceeding 20° will probably give definite elevator locking as a result of unporting.

Effect of Tab

The effect of a 20-percent-chord tab on the plain sealed elevator is shown in figure 8. The spin conditions and tail-plane plan form were the same as for the preceding computations which were made to show the effects of nose balance. It is seen that a 10° up deflection of the trimming tab reduces by about 50 percent the force required to neutralize the elevator. A balancing tab would increase the forces until the stick was forward of neutral.

Effect of Angle of Yaw

Owing to the Limitations of the data, the effect of yaw angle on stick forces could be determined for only two elevator deflections (fig. 9). The spin and tail-plane plan form were the same as for the previous case. The curves show that for the plain elevator the stick forces remain constant up to an angle of yaw of 10° . Between yaw angles of 10° and 25° there is a small change in force in a direction which would tend to move the stick back. Other balance types are also shown (reference 1) to be insensitive to yaw up to 10° .

Applications to Specific Airplanes

The experimental results obtained from the investigation of reference 1 were also utilized in estimating the stick forces in the normal spin for four modern pursuit airplanes. The dimensional Characteristics of the tail planes are given in table I, the plan forms are shown in figures 2 to 5, and the normal spin characteristics of these airplanes (based on spin-tunnel tests) are shown in table II. Results for airplane A and airplane B, which have approximately 21-percent and 25-percent blunt-nose balances, respectively, were obtained by interpolation between the values for the 35-percent blunt-nose balance and for the plain elevator (taken to have 9-percent balance). Airplane C, which had a shielded horn balance, was considered to have two elements - one with a plain balance and the other with an unsealed 50-percent blunt-nose balance.

The computed stick forces were compared with the curve of figure 6 showing the maximum push an average pilot could exert with one hand (average of the attitudes for the cockpit level and the cockpit nosed 90° down). This push is

called the "allowable force" on figure 10. The effect of yaw angle on hinge moments is not included and the elevator is assumed to have tab neutral. The yaw angles at the tail did not exceed 15° ; as a result, their effects would be slight.

The forces required to move the stick forward on airplanes A and B remain smaller than the allowable force for practically the whole elevator range studied, and it is probable that the elevator can be safely neutralized on the two airplanes. On the other hand, airplanes C and D have much higher stick forces, and it is doubtful that the elevator can be pushed more than three-fourths of the distance to neutral from its full-up position. It appears unlikely that the pilot can abruptly push the stick forward of neutral for any of these airplanes. It should be remembered, however, that the reversal of the rudder and partial forward movement of the stick, as normally used for recovery, may alter the spin and the magnitude of the stick force.

In figure 11, the stick force required to neutralize the elevator is plotted as a function of angle of attack in the spin. It can be seen that the stick force increased as the spins steepened. This increase is a result of the increased airspeeds associated with the steeper spins.

For airplanes C and D the percentage of change in stick force over the angle-of-attack range from 35° to 45° was small because the percentage of change in velocity was small for these models. The decrease, in absolute value of the hinge-moment coefficient with decreasing angle of attack tended to compensate for the effect of the increased airspeed.

Pilots have frequently reported high stick forces for spins of current airplanes. In this connection it should be noted that, although an average pilot can push 110 pounds, flight-test reports indicate that pilots consider 50 pounds a heavy force and prefer to use two hands for forces exceeding this value. The high stick forces shown for airplane C were substantiated in flight in that the test pilot found that in a spin he was unable to push the stick forward using two hands.

In order to extend the study of control forces in spins, it would be desirable to obtain considerable additional data on rudder and elevator hinge moments at high angles of attack. Information is required for a greater range of angles of

attack, for other balance types, and for other fuselage-tail combinations. These data would also furnish information on the problem of rudder locking in normal flight conditions.

CONCLUSIONS

The present analysis, which is based on the direct application of data obtained for one specific tail plane, leads to the following conclusions regarding elevator stick forces in spins:

1. Although nose balance will reduce the force required to neutralize the elevator, there is danger of elevator locking in the full-up position for large balances.

2. The stick force to neutralize the elevator can be materially reduced by use of the trimming tab.

3. Elevator forces on several current airplanes may be so high that the pilot will be unable to push the stick to the neutral position. This tendency will be detrimental for cases in which elevator-down movement is essential for recovery.

4. Stick forces will be greater for steeper spins.

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REFERENCES

1. Sears, Richard I., and Hoggard, H. Page, Jr.: Characteristics of Plain and Balanced Elevators on a Typical Pursuit Fuselage at Attitudes Simulating Normal-Plight and Spin Conditions. NACA A.R.R., March 1942.
2. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. T.N. No. 550, NACA, 1936.

TABLE I. - DIMENSIONAL CHARACTERISTICS OF THE
TAIL PLANES OF THE TEST AIRPLANES
[Nose balance unsealed]

Airplane	Elevator dimensions			Approximate nose balance (percent)
	Area (sq ft)	Root- mean- square chord (ft)	Mean chord (ft)	
Tail plane of reference 1	0.48	0.20	0.19	-----
A	18.20	1.28	1.14	21-percent blunt nose
B	15.40	1.37	1.20	25-percent blunt nose
C	{ 20.82 2.84	1.67	1.43	Plain elevator
		.97		50-percent blunt nose
D	18.70	1.40	1.37	Plain elevator

TABLE II.- SPIN CHARACTERISTICS OF THE TEST AIRPLANES

Air- plane	α (deg)	ϕ^1 (deg)	Ω (radians/sec)	Vertical velocity V (ft/sec)	Radius of spin at tail, R_T (ft)	Yaw angle at tail, ψ (deg)
A	38	2D	2.67	226	19.59	11.0
B	30	9D	2.88	244	15.60	1.0
C	50	1D	2.68	189	19.55	16.0
D	37	3D	2.58	238	17.82	8.0

¹D indicates that the inner wing is down.

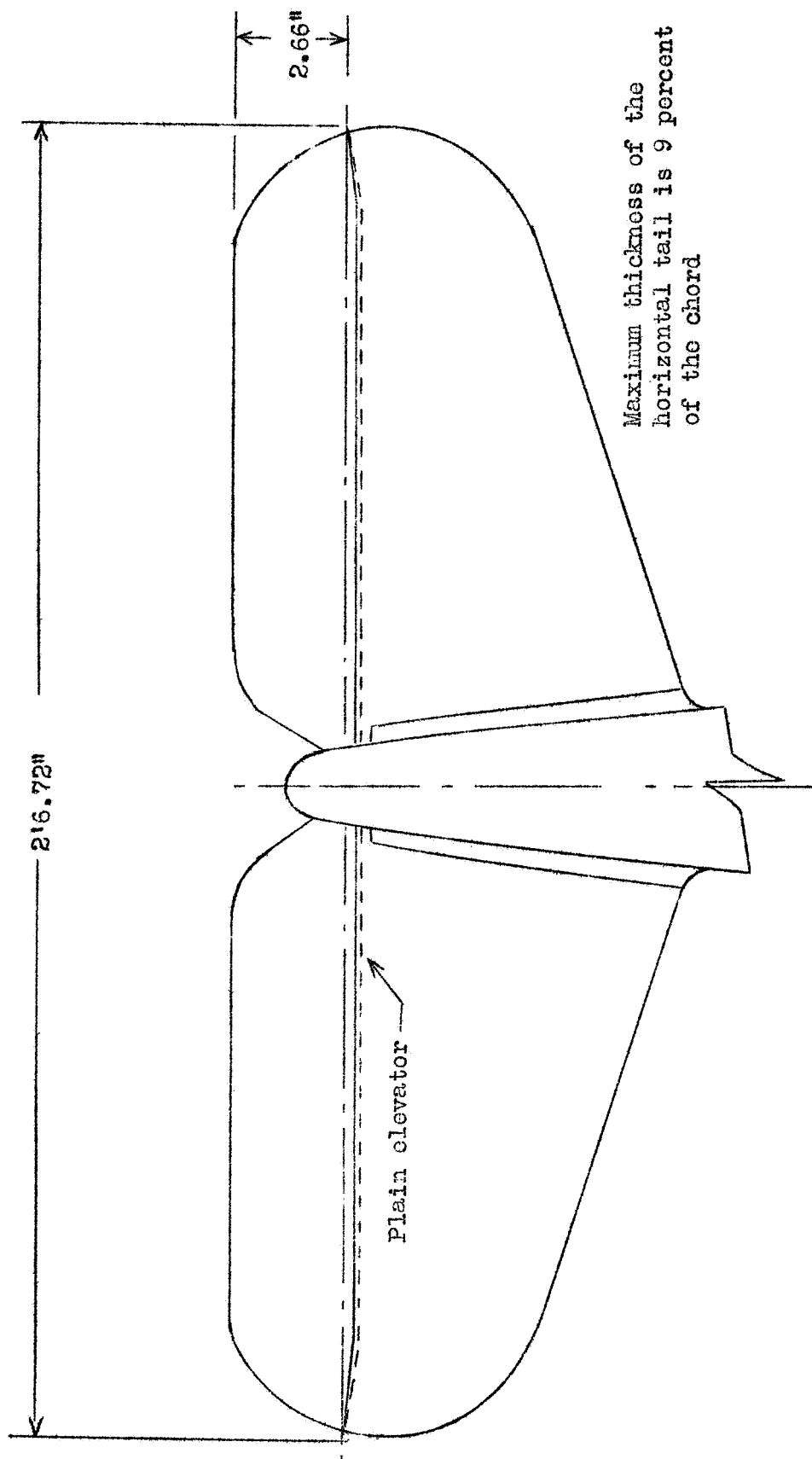


Figure 1.-- Tail plane used in tests of reference 1.

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16'10"

6'11.00"

24.00"

3.12"

18.80"

10.46"

Maximum thickness of the
horizontal tail is 9 percent
of the chord

All dimensions given
are full-scale values

Fig. 2

Figure 2.- Horizontal tail of airplane A, 1/20 scale.

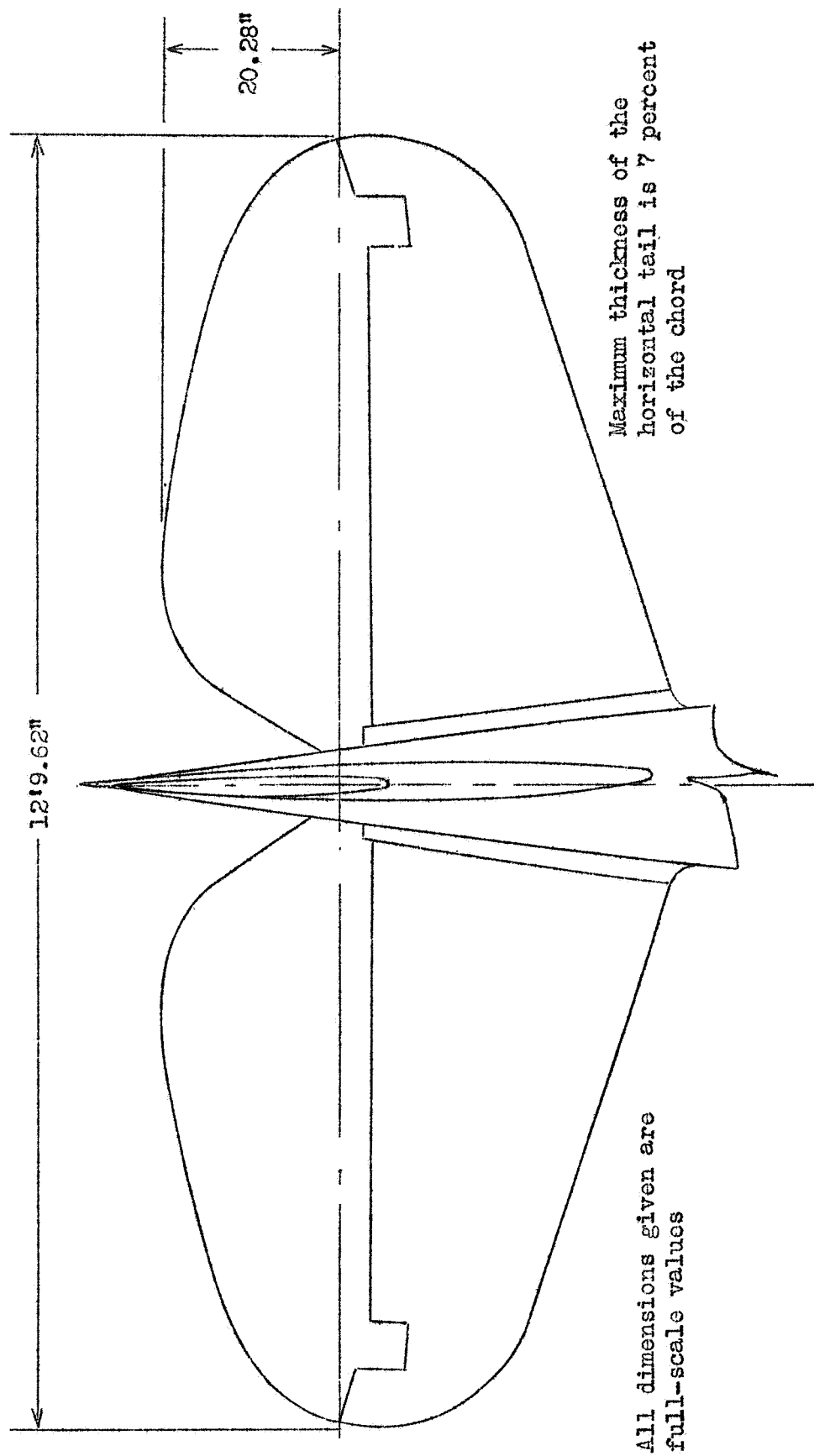


Figure 3.-- Horizontal tail of airplane B, 1/20 scale.

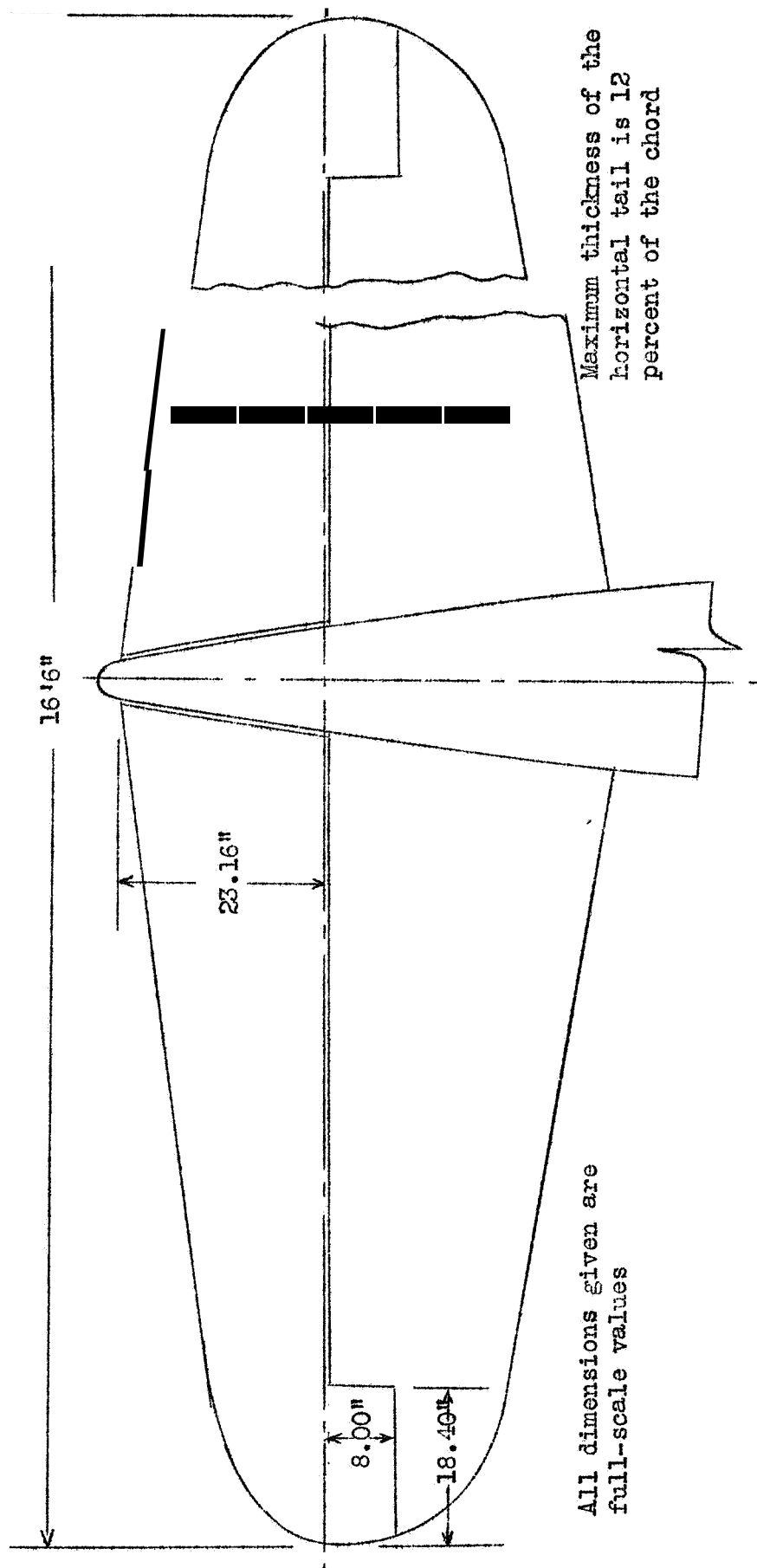


Figure 2-- Horizontal tail of airplane C, 1/20 scale.

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Fig. 5

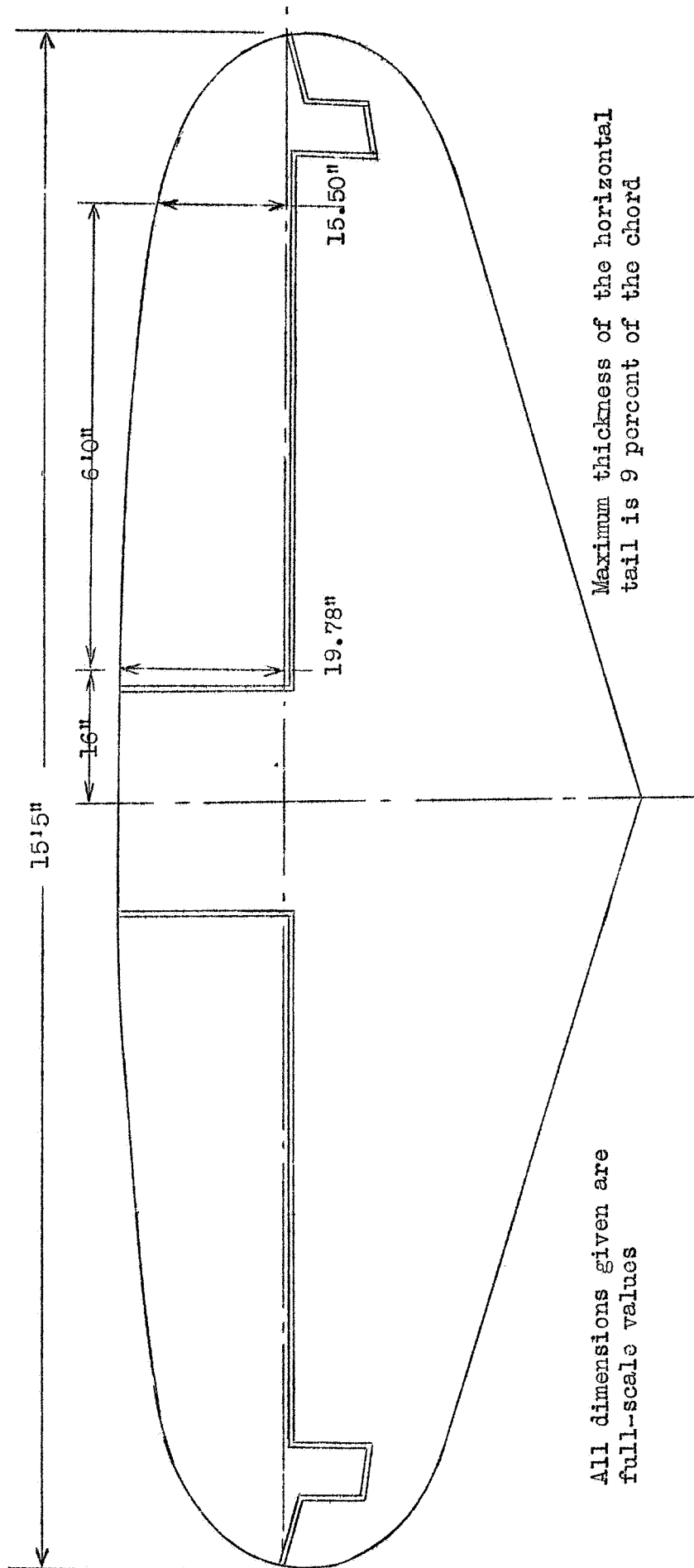


Figure 5.- Horizontal tail of airplane D, 1/20 scale.

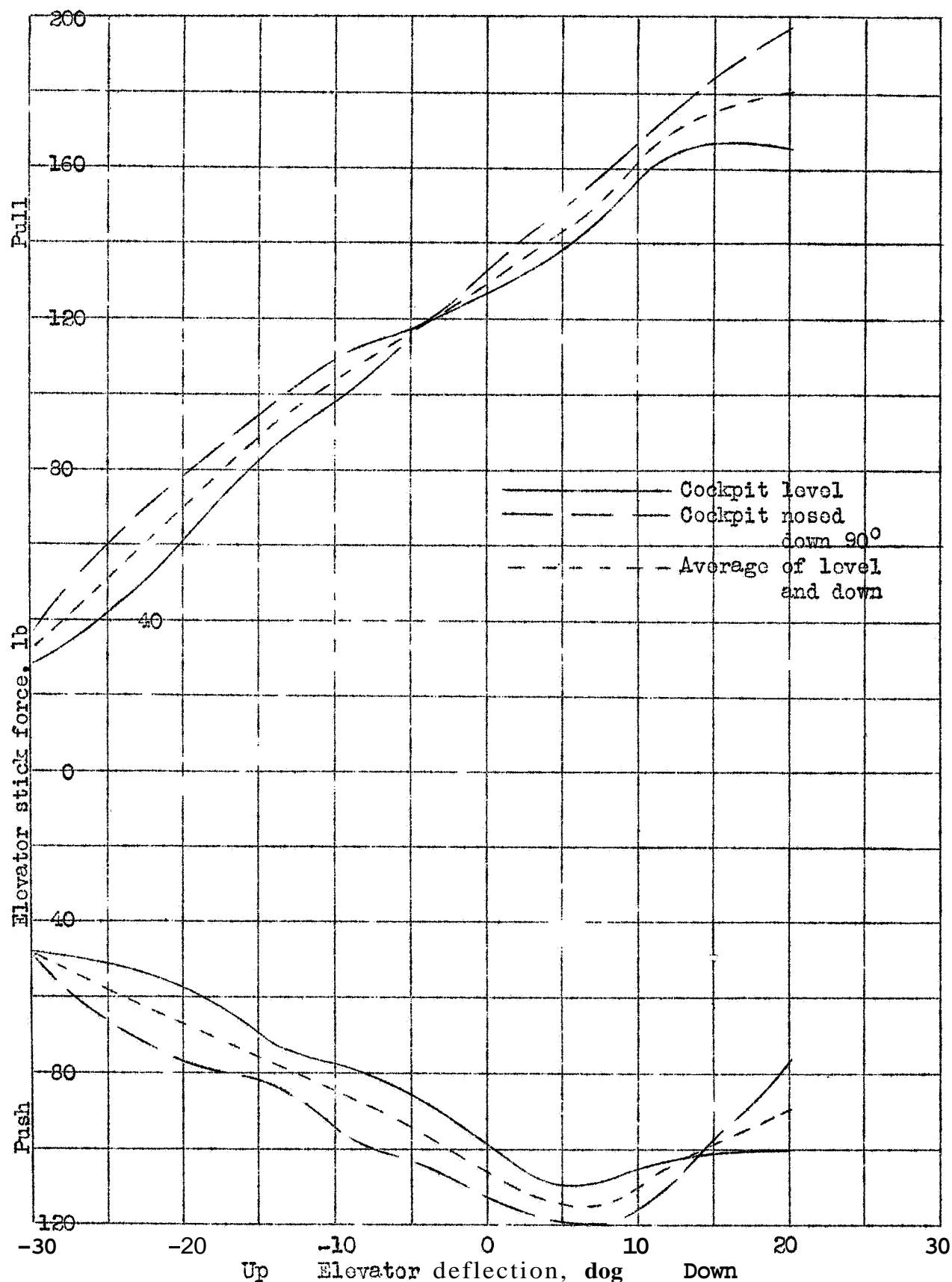


Figure 6.-- Limitations of the forces a pilot can exert (average for two pilots from results of reference 2).

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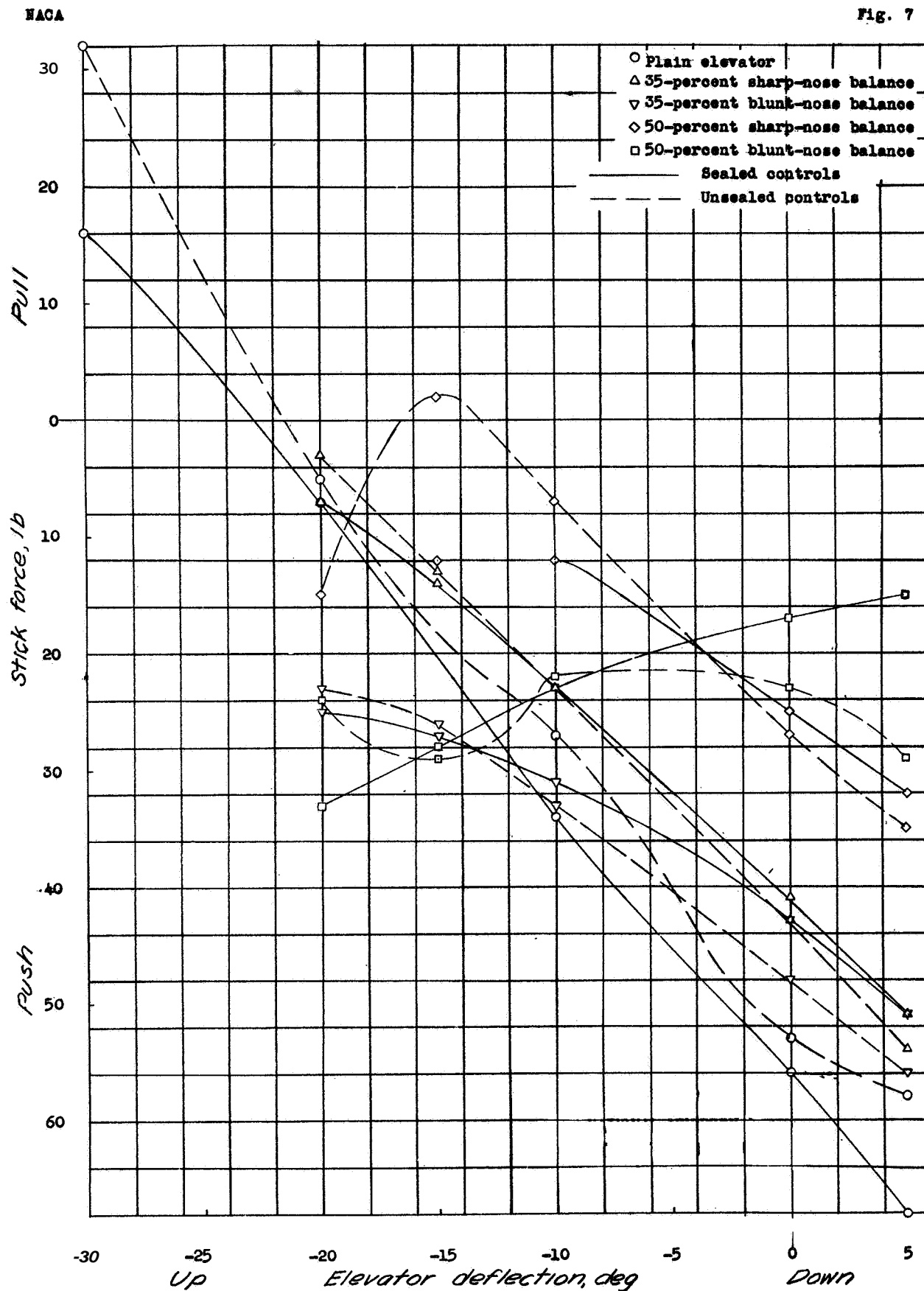


Figure 7.- Variation of stick force with elevator deflection for several nose balances on the P-36A airplane in a typical spin. Tab neutral; α , 45° ; V, 161 feet per second; altitude, 12,000 feet.

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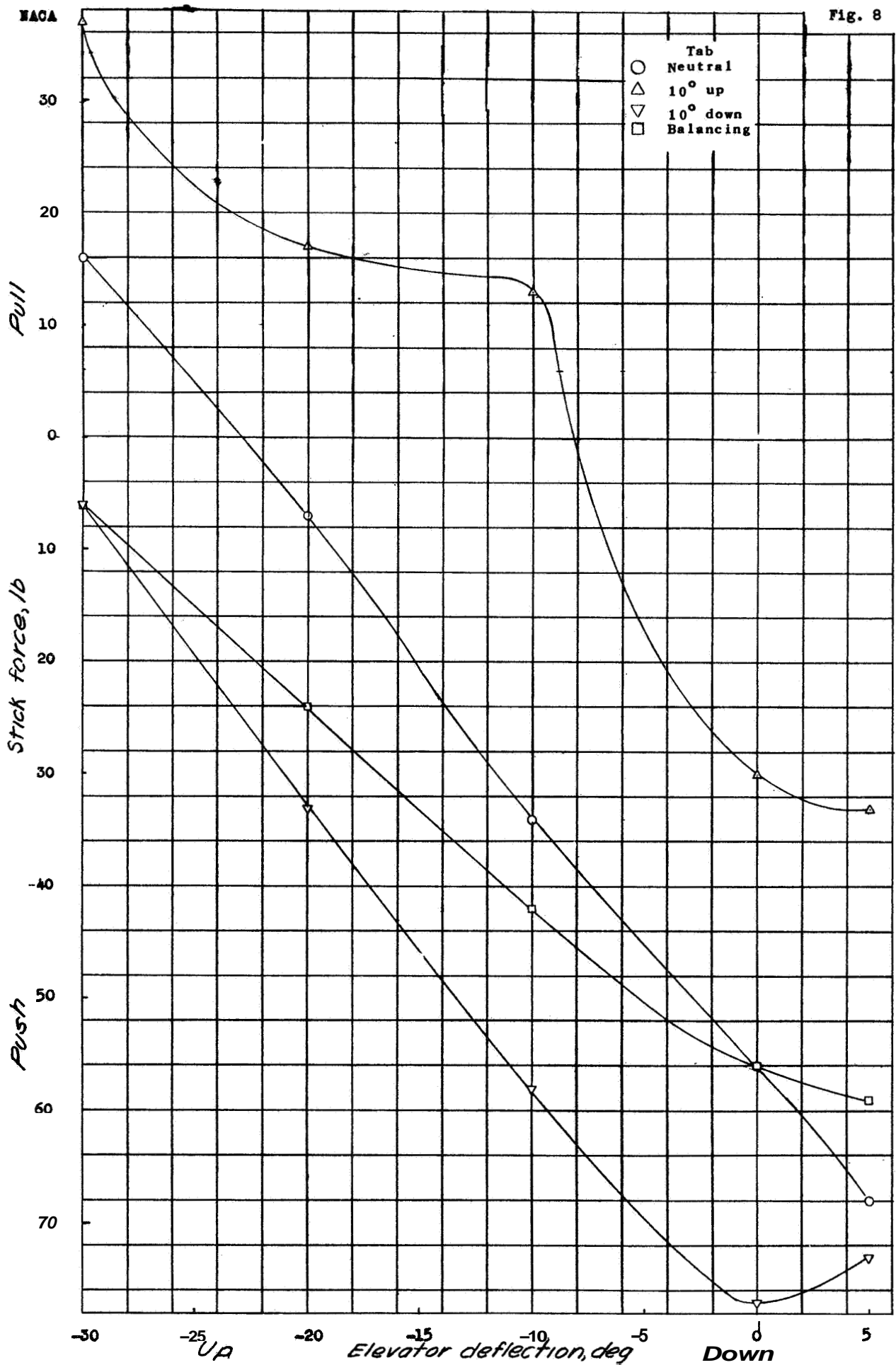


Figure 8.- Variation of stick force with elevator deflection showing the effect of a 20-percent-chord tab for the P-36A airplane in a typical spin. Plain sealed elevator; α , 45° ; V , 161 feet per second; altitude, 12,000 feet.

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Fig. 9

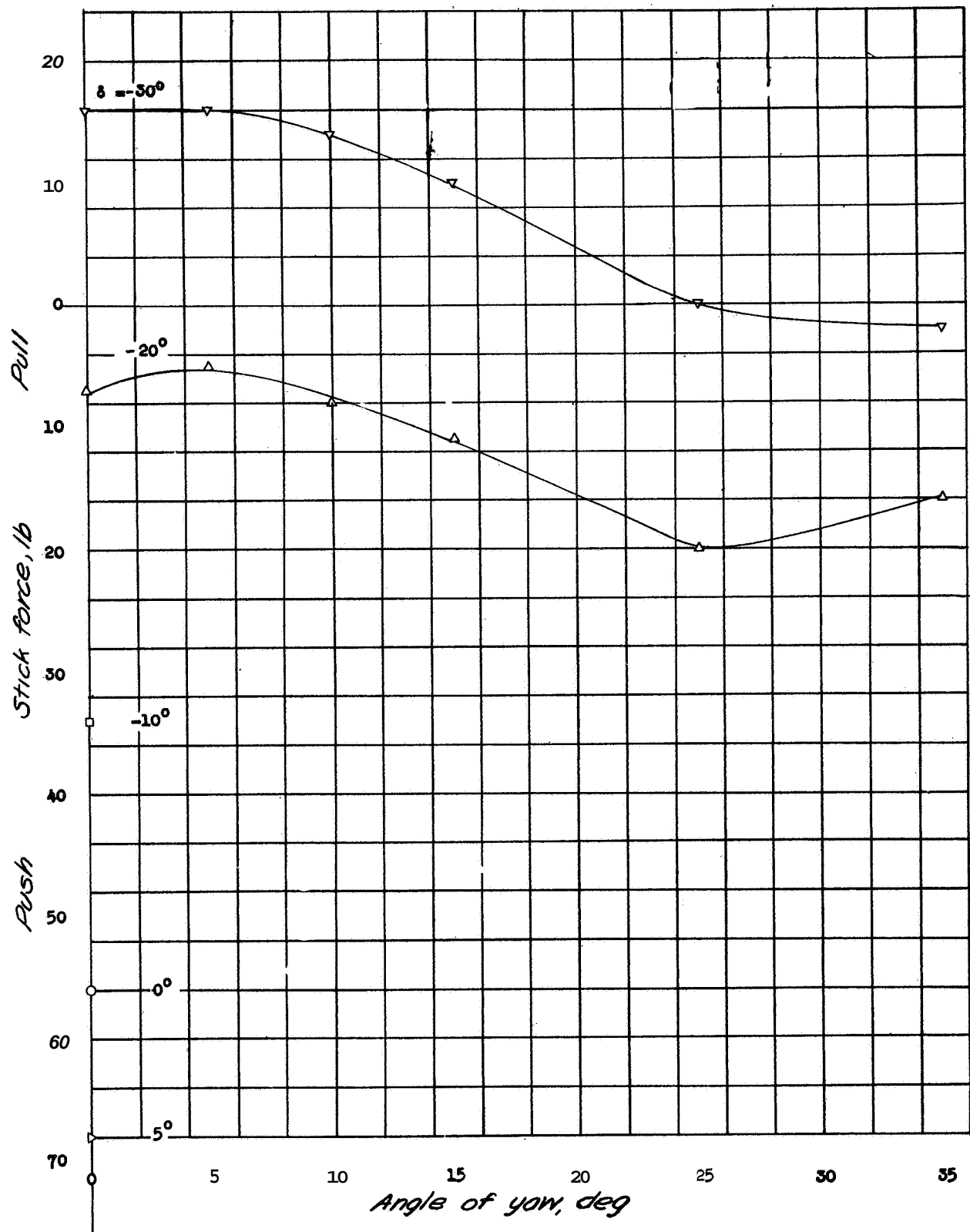
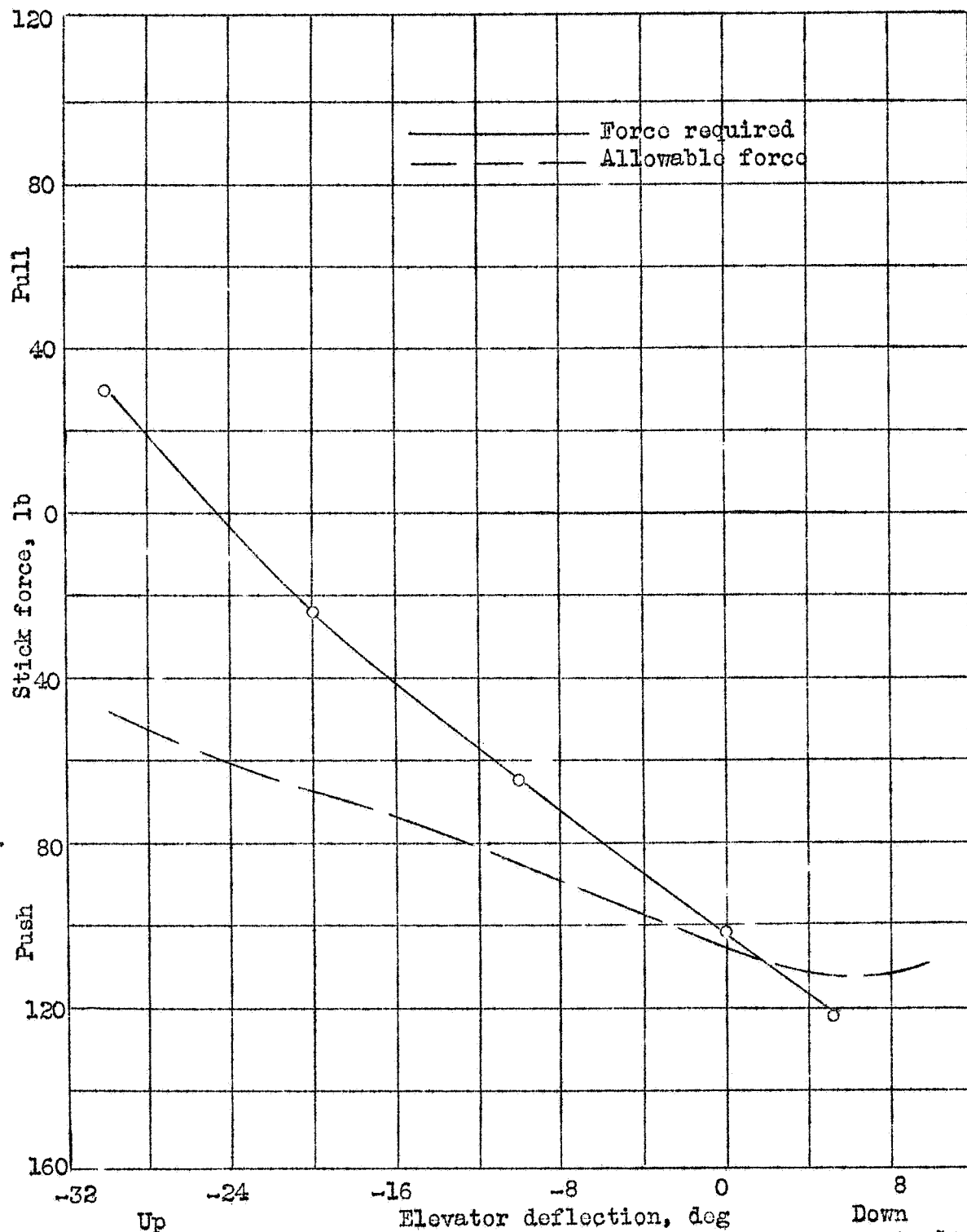
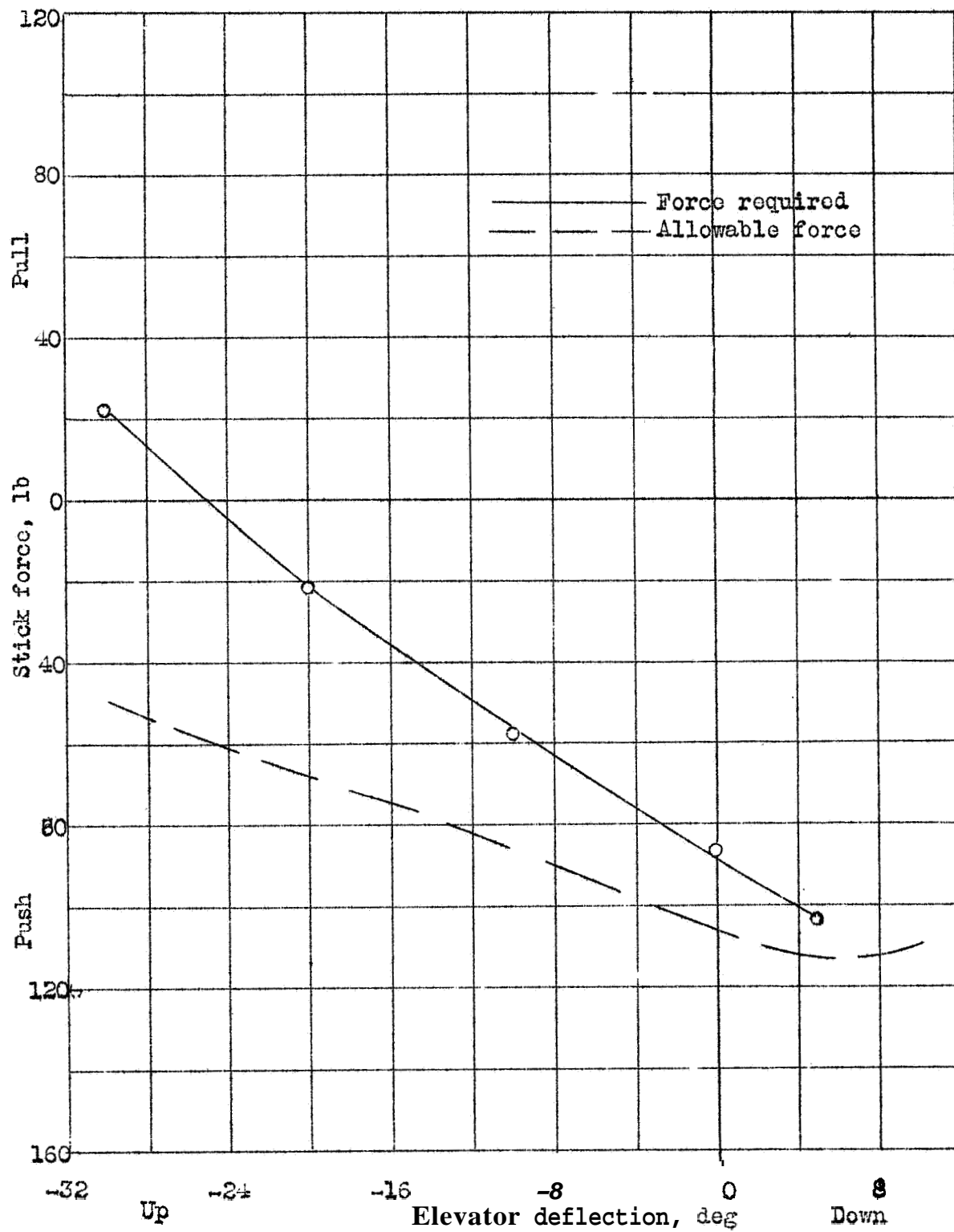


Figure 9.- Variation of stick force with angle of yaw for the P-36A airplane in a typical spin. Plain sealed elevator; tab neutral; α , 45° ; V , 161 feet per second; altitude, 12,000 feet.



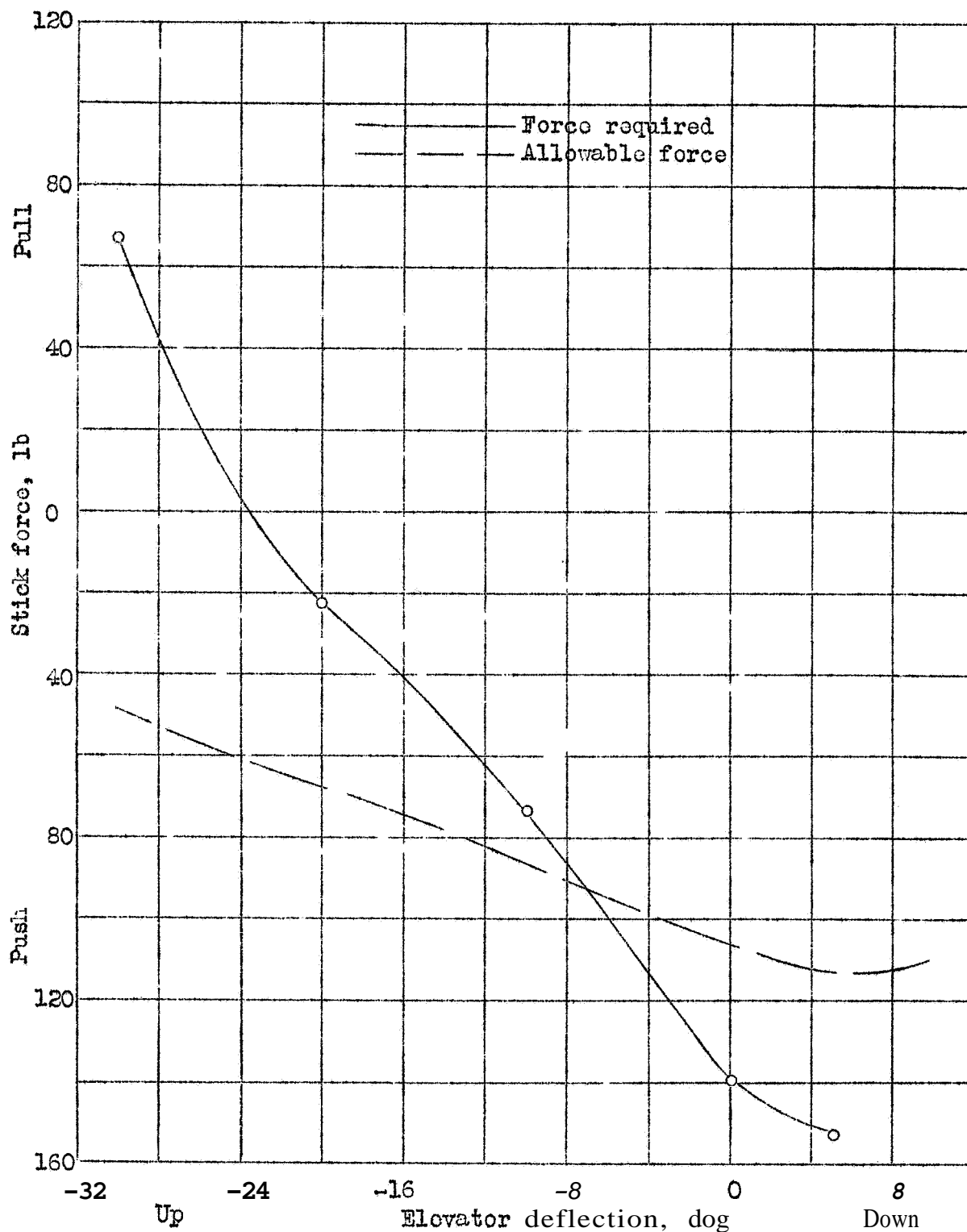
(a) Airplane A. Unsealed 21-percent blunt-nose balance; tab neutral; α , 38° ; V , 232 feet per second; altitude, 10,000 feet.

Figure 10(a to d).-- Variation of stick force with elevator deflection for airplanes in normal spinning attitudes.



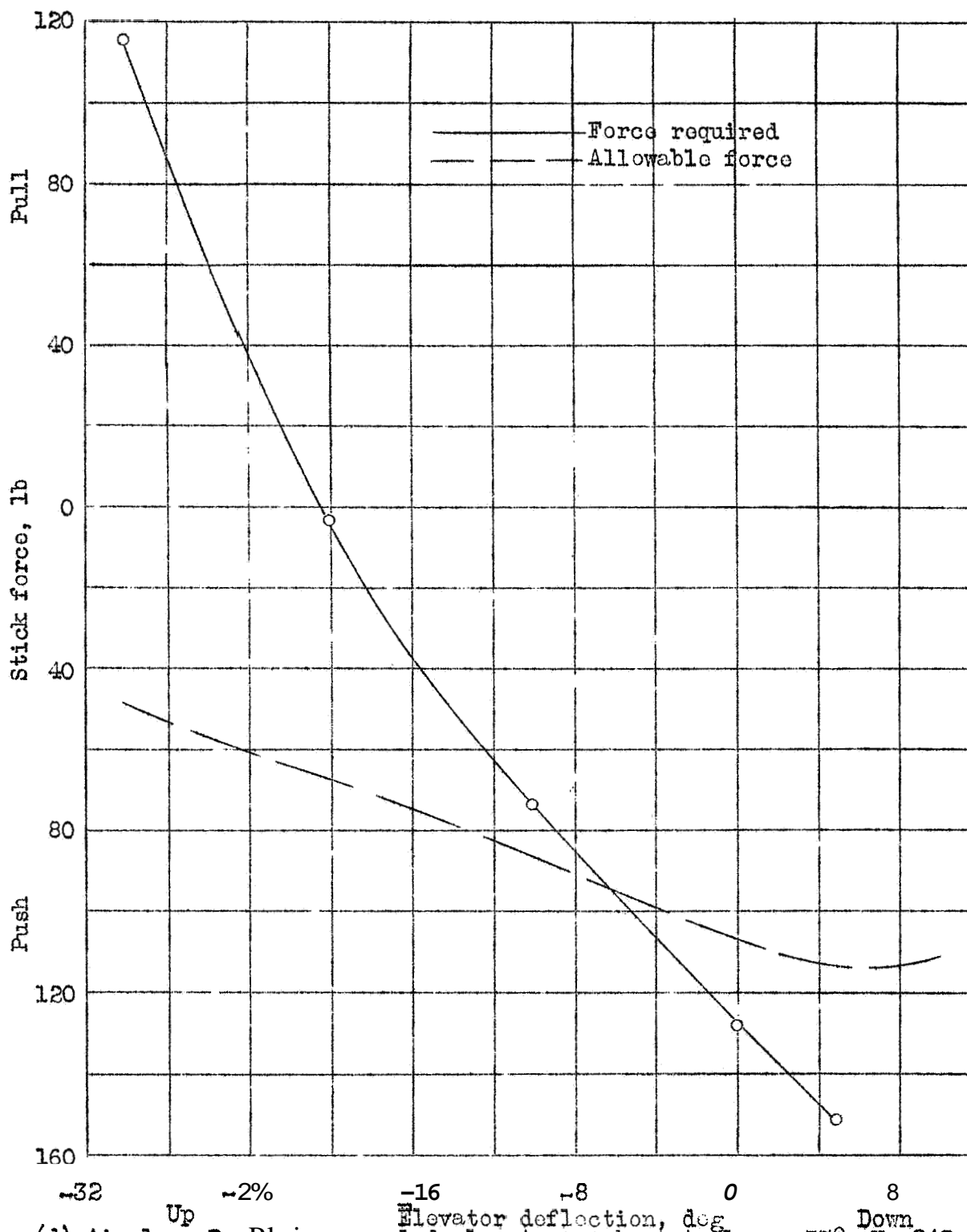
(b) Airplane B. Unsealed 25-percent blunt-nose balance; tab neutral:
a, 30° ; V, 248 feet per second; altitude, 12,000 feet.

Figure 10.- Continued.



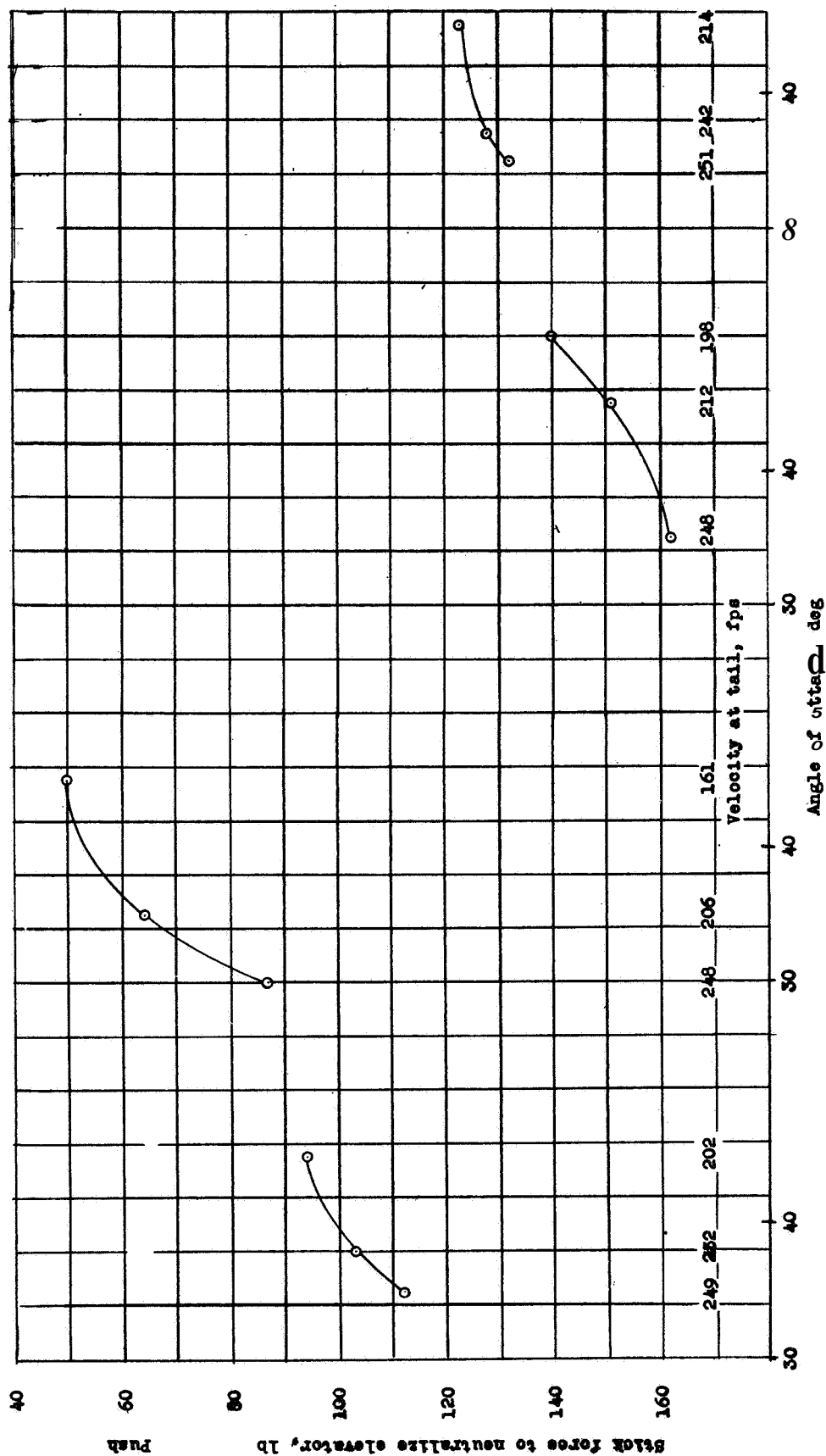
(c) Airplane C. Combination of 50-percent blunt-nose balance and plain elevator; tab neutral; α , 50° ; V , 198 foot per second; altitude, 12,000 foot.

Figure 10.- Continued.



(d) Airplane D. Plain unsealed elevator; tab neutral; α , 37° ; V , 242 feet per second; altitude, 10,000 feet.

Figure 10.- Concluded.



(a) Airplane A. Unsealed
21-percent blunt-nose
balance; tab neutral.

(b) Airplane B. Unsealed
25-percent blunt-nose
balance; tab neutral.

(c) Airplane C. Combination
of 50-percent blunt-
nose balance and plain
elevator; tab neutral.

(d) Airplane D. Plain
unsealed elevator;
tab neutral.

Figure 11.- Stick force to neutralize elevator at various angles of attack.